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PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANT : Gerald E. Rains et al.  
PATENT NO.: 6,917,206  
ISSUED : July 12, 2005  
TITLE : MULTIPLE FREQUENCY GRAIN MOISTURE SENSOR FOR  
COMBINES  
Conf. No. : 8999  
Docket No.: P05388US1-15694

**Certificate**  
JAN 04 2006  
**of Correction**

Mail Stop Certificate of Correction  
Commissioner of Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Dear Sir:

**REQUEST FOR RECONSIDERATION OF APPLICANT'S  
REQUEST FOR CERTIFICATE OF CORRECTION FOR  
PATENT NO. 6,917,206 UNDER 37 C.F.R. § 1.322.(a)**

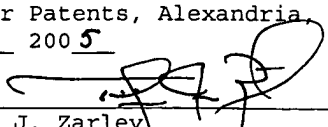
It is requested the Commissioner reconsider Applicant's request and issue a Certificate of Correction in the above-identified patent. A soft copy of the patent is attached.

Attached in duplicate is Form PTO/SB/44 with at least one copy being suitable for printing. The exact page and paragraph where the errors occurred in the patent are shown below:

Column 14, line 29, strike the numeral "6" and insert the numeral -12-.

-----  
CERTIFICATE OF MAILING (37 C.F.R. § 1.8(a))

I hereby certify that this document and the documents referred to as enclosed therein are being deposited with the United States Postal Service as First Class mail addressed to: Commissioner for Patents, Alexandria, VA 22313-1450, on this 27th day of December 2005

  
\_\_\_\_\_  
Timothy J. Zarley

JAN 06 2006

Column 14, line 39, strike the numeral "5" and insert the numeral -1-.

Column 14, line 43, strike the numeral "5" and insert the numeral -1-.

Column 14, line 47, strike the numeral "5" and insert the numeral -1-.

Column 14, line 49, strike the numeral "5" and insert the numeral -1-.

As original filed, the application had claims 1-26. By preliminary amendment on November 20, 2003, claims 1-12 and 22-26 were cancelled leaving claims 13-21 for prosecution.

On October 10, 2004, the Examiner issued a restriction requirement and in response the Applicant, with traverse, elected claims 13-15 and withdrew claims 16-21. In addition, the Applicant added new claims 27-32.

As a result of a telephone interview with Timothy J. Zarley on December 13 and 14, 2004, the Examiner issued an Examiner's amendment (see attached) where claims 28, 31 and 32 were amended to depend from claim 13 instead of withdrawn claim 16; claim 29 was amended to depend from claim 28 instead of withdrawn claim 17; and claim 30 was amended to depend from claim 27 instead of withdrawn claim 16.

Subsequent to this, the Examiner withdrew the restriction requirement and allowed claims 13-21 and 27-32. The amended claims 28, 29, 30, 31, and 32 are claims 12, 8, 13, 14, and 15 respectively in the printed patent. As amended these claims should depend from claims 1, 12, 4, 1 and 1 respectively.

Since this was a Patent Office error, no government fee is required. If any fees are believed to be due in

connection with this request, charge any additional fees to  
Deposit Account 50-2098,

It is requested that the Certificate of Correction  
issue. Please send the Certificate to the undersigned.

Respectfully submitted,

A handwritten signature in dark ink, appearing to read 'TJZ', with a horizontal line drawn through the middle of the letters.

Timothy J. Zarley  
Reg. No. 45,253  
ZARLEY LAW FIRM, P.L.C  
Capital Square  
400 Locust Street, Suite 200  
Des Moines, IA 50309-2350  
Phone No. (515) 558-0200  
Fax No. (515) 558-7790  
Customer No. 34082  
Attorneys of Record

- TJZ/jlk -



# UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE  
United States Patent and Trademark Office  
Address: COMMISSIONER FOR PATENTS  
P.O. Box 1450  
Alexandria, Virginia 22313-1450  
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
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10/7/8,147

11/20/2003

Gerald E. Rains

P05388US1

8999

34082

7590

12/20/2004

ZARLEY LAW FIRM P.L.C.  
CAPITAL SQUARE  
400 LOCUST, SUITE 200  
DES MOINES, IA 50309-2350



EXAMINER

NGUYEN, VINCENT Q

ART UNIT

PAPER NUMBER

2858

DATE MAILED: 12/20/2004

Please find below and/or attached an Office communication concerning this application or proceeding.

**UNITED STATES PATENT AND TRADEMARK OFFICE  
CERTIFICATE OF CORRECTION**Page 1 of 1

PATENT NO. : 6,917,206  
APPLICATION NO.: 10/718,147  
ISSUE DATE : July 12, 2005  
INVENTOR(S) : Gerald E. Rains, et al.

It is certified that an error appears or errors appear in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 14, line 29, strike the numeral "6" and insert the numeral -12-.

Column 14, line 39, strike the numeral "5" and insert the numeral -1-.

Column 14, line 43, strike the numeral "5" and insert the numeral -1-.

Column 14, line 47, strike the numeral "5" and insert the numeral -1-.

Column 14, line 49, strike the numeral "5" and insert the numeral -1-.

**MAILING ADDRESS OF SENDER (Please do not use customer number below):**

Mr. Timothy J. Zarley, Zarley Law Firm, P.L.C.  
Capital Square, 400 Locust Street, Suite 200  
Des Moines, IA 50309-2350

This collection of information is required by 37 CFR 1.322, 1.323, and 1.324. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 1.0 hour to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Attention Certificate of Corrections Branch, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

*If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.*

**JAN 06 2006**

**UNITED STATES PATENT AND TRADEMARK OFFICE  
CERTIFICATE OF CORRECTION**Page 1 of 1

PATENT NO. : 6,917,206

APPLICATION NO.: 10/718,147

ISSUE DATE : July 12, 2005

INVENTOR(S) : Gerald E. Rains, et al.

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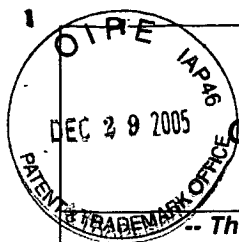
**MAILING ADDRESS OF SENDER (Please do not use customer number below):**

Mr. Timothy J. Zarley, Zarley Law Firm, P.L.C.  
Capital Square, 400 Locust Street, Suite 200  
Des Moines, IA 50309-2350

This collection of information is required by 37 CFR 1.322, 1.323, and 1.324. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 1.0 hour to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Attention Certificate of Corrections Branch, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

*If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.*

JAN 06 2006



## Office Action Summary

Application No.

10/718,147

Applicant(s)

RAINS ET AL.

Examiner

Vincent Q Nguyen

Art Unit

2858

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --  
Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If the period for reply specified above is less than thirty (30) days, a reply within the statutory minimum of thirty (30) days will be considered timely.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

### Status

- 1) ☐ Responsive to communication(s) filed on \_\_\_\_.
- 2a) ☐ This action is **FINAL**. 2b) ☒ This action is non-final.
- 3) ☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

### Disposition of Claims

- 4) ☒ Claim(s) 13-21 and 27-32 is/are pending in the application.
- 4a) Of the above claim(s) 16-21 is/are withdrawn from consideration.
- 5) ☐ Claim(s) \_\_\_\_ is/are allowed.
- 6) ☒ Claim(s) 13-15 and 27-32 is/are rejected.
- 7) ☐ Claim(s) \_\_\_\_ is/are objected to.
- 8) ☐ Claim(s) \_\_\_\_ are subject to restriction and/or election requirement.

### Application Papers

- 9) ☒ The specification is objected to by the Examiner.
- 10) ☐ The drawing(s) filed on \_\_\_\_ is/are: a) ☐ accepted or b) ☐ objected to by the Examiner.  
Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).  
Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).
- 11) ☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

### Priority under 35 U.S.C. § 119

- 12) ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).  
a) ☐ All b) ☐ Some \* c) ☐ None of:
- ☐ Certified copies of the priority documents have been received.
  - ☐ Certified copies of the priority documents have been received in Application No. \_\_\_\_.
  - ☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

\* See the attached detailed Office action for a list of the certified copies not received.

### Attachment(s)

- 1) ☒ Notice of References Cited (PTO-892)
- 2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)
- 3) ☒ Information Disclosure Statement(s) (PTO-1449 or PTO/SB/08)  
Paper No(s)/Mail Date 03/01/2004.
- 4) ☒ Interview Summary (PTO-413)  
Paper No(s)/Mail Date. \_\_\_\_.
- 5) ☐ Notice of Informal Patent Application (PTO-152)
- 6) ☐ Other: \_\_\_\_.



Continuation of Substance of Interview including description of the general nature of what was agreed to if an agreement was reached, or any other comments:

Examiner wondered if the amendment of claims 13-21 and 27-32 or the remark is typographical error. In the remark, Applicant indicated to add new claims 27-32 that depend on claim 13. However, in the amendment of the claims, claims 28, 30-32 depend on claim 16 (Withdrawn claim) and claim 29 depends on claim 17 (Also being withdrawn).

Applicant called back (12/14/2004) and explained that claims 28, 31, 32 depend on claim 13. claim 29 depend on claim 28. Claim 30 depends on claim 27.

Examiner will fix the claims 28-32 in accordance to the telephone interview. Therefore, claims 28, 31 and 32 depend on claim 13. Claim 29 depends on claim 28. Claim 30 depends on claim 27.

If the case is allowable, Applicant authorized the examiner to cancel the non-elected claims 16-21.

**DETAILED ACTION**

***Election/Restrictions***

1. Applicant's election of claims 13-15 and 27-32 in the reply filed on 11/12/2004 is acknowledged. Because applicant did not distinctly and specifically point out the supposed errors in the restriction requirement, the election has been treated as an election without traverse (MPEP § 818.03(a)). The Election/Restrictions requirement is still deemed proper and is thus made FINAL.

Claims 16-21 are withdrawn from further consideration pursuant to 37 CFR 1.142(b), as being drawn to a nonelected invention, there being no allowable generic or linking claim.

**EXAMINER'S AMENDMENT**

2. An examiner's amendment to the record appears below. Should the changes and/or additions be unacceptable to applicant, an amendment may be filed as provided by 37 CFR 1.312. To ensure consideration of such an amendment, it MUST be submitted no later than the payment of the issue fee.

Authorization for this examiner's amendment was given in a telephone interview with Timothy J. Zarley on December 13 and 14, 2004.

3. In the amendment of claims filed 11/12/2004, the claims are amended as follows:

In claims 28, 31, 32, lines 1, replace 16 with 13 (To make the claims depend on claim 13 instead of claim 16).

Art Unit: 2858

In claim 29, line 1, replace 17 with 28 (To make the claim depend on claim 28 instead of 17).

In claim 30, line 1, replace 16 with 27 (To make the claim depend on claim 27 instead of 16).

### ***Specification***

4. Applicant is reminded of the proper language and format for an abstract of the disclosure.

The abstract should be in narrative form and generally limited to a single paragraph on a separate sheet within the range of 50 to 150 words. It is important that the abstract not exceed 150 words in length since the space provided for the abstract on the computer tape used by the printer is limited. The form and legal phraseology often used in patent claims, such as "means" and "said," should be avoided. The abstract should describe the disclosure sufficiently to assist readers in deciding whether there is a need for consulting the full patent text for details.

The language should be clear and concise and should not repeat information given in the title. It should avoid using phrases which can be implied, such as, "The disclosure concerns," "The disclosure defined by this invention," "The disclosure describes," etc.

5. The abstract of the disclosure is objected to because it should be on a separate sheet. Further, the abstract should include which is new in the art to which the invention pertains (Elements such as a guard proximate to the parallel to the sense plate ... etc.

in the abstract of previous Applications should be removed). Correction is required.  
See MPEP § 608.01(b).

***Claim Rejections - 35 USC § 102***

6. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

A person shall be entitled to a patent unless –

(b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

7. Claims 13, 15, 28, 31, 32, are rejected under 35 U.S.C. 102(b) as being anticipated by Nelson et al. (5,218,309).

Regarding claims 13, 31, Nelson et al. discloses a method comprising the step of selecting a frequency from a plurality of frequencies (Any first frequency of the two frequencies (column 2, line 9; column 3, line 8) being applied to the system); applying the frequency to a parallel plate cell filled with grain (Column 2, lines 61-68); measuring a first complex admittance of the parallel plate cell filled with grain (Column 2, lines 3-15); applying the frequency to reference (Nelson et al. does not explicitly disclose but inherent that the frequency is reference to the second frequency for comparison); measuring a second complex admittance of the reference (Column 3, lines 16-17; see also table 1); computing a complex permittivity from the first complex admittance and the second complex admittance (Entire column 4).

Regarding claims 15, 32, Nelson et al. discloses the step of selecting the second reference admittance from a plurality of reference admittances (Column 3, lines 52-54).

Regarding claim 28, Nelson et al. discloses the step of using a plurality of references (Phase angle, capacitance, reactance; column 3, lines 10-15) determine one or more distortion characteristics of measuring the real and imaginary components (The distortion is any measured value outside of the curves in figure 1).

***Claim Rejections - 35 USC § 103***

8. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

(a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negated by the manner in which the invention was made.

9. Claim 14 is rejected under 35 U.S.C. 103(a) as being unpatentable over Nelson et al. (5,218,309) in view of Funk et al. (4,584,655).

Regarding claims 14, Nelson et al. does not disclose the step of applying a calibration factor to the reference admittance to calculate an empty cell admittance.

Funk et al. discloses a moisture tester and further discloses the step of applying a calibration factor to the reference admittance to calculate an empty cell admittance (Funk et al.'s column 7, lines 29-32) for the purpose of enhancing the moisture tester (Funk et al.'s column 3, lines 22-26).

It would have been obvious to one of ordinary skill in the art at the time the invention was made to incorporate the step of applying a calibration factor to the reference admittance as taught by Funk et al. into the system of Nelson because calibration would enhance the accuracy for determining the moisture.

10. Claims 27, 30, are rejected under 35 U.S.C. 103(a) as being unpatentable over Nelson et al. (5,218,309) in view of Brown et al. (3,870,951).

Regarding claims 27, 30, Nelson et al. disclose the step of measuring real and imaginary components (Table 1) of an excitation voltage having a frequency applied driven plate parallel plate measuring real and imaginary components (Column 5, lines 1-8); calculating the first complex admittance (Y) of the parallel plate cell; calculating the second complex admittance of reference admittance; and calculating a grain complex permittivity (Table 1).

Nelson et al. does not disclose the step of measuring a sense current sensed at a sense plate of the parallel plate cell.

Brown et al. discloses a moisture measuring probe and further discloses the step of measuring a sense current sensed at parallel plate cell (Brown et al.'s column 1, lines 8-11).

It would have been obvious to one of ordinary skill in the art at the time the invention was made to incorporate the step of measuring a sense current sensed at parallel plate cell into the system of Nelson because it is a routine to measure the moisture (Brown et al.'s column 1, lines 9-11).

11. Claim 29 is rejected under 35 U.S.C. 103(a) as being unpatentable over Nelson et al. (5,218,309) in view Myers (5,561,250).

Regarding claim 29, Nelson does not disclose the step of correcting for the determined distortion characteristics.

Myers discloses a system and method similar to that of Nelson et al. and further discloses a step of correcting the distortion (Meyers's column 5, lines 49-50) for the purpose of improve accuracy of the measurement (Meyers's column 5, line 9-10).

It would have been obvious to one of ordinary skill in the art at the time the invention was made to incorporate the step of correcting the distortion as taught by Myers into the system of Nelson et al. because it would have been desirable to improve the accuracy of the moisture measurement.

#### ***Contact Information***


12. Any inquiry concerning this communication or earlier communications from the examiner should be directed to Vincent Q Nguyen whose telephone number is (571) 272-2234. The examiner can normally be reached on 8:30-5:00.

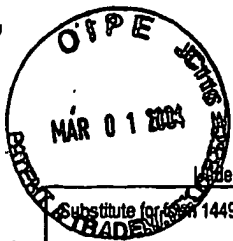
If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, N. Le can be reached on (571) 272-2233. The fax phone number for the organization where this application or proceeding is assigned is 703-872-9306.

Art Unit: 2858

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see <http://pair-direct.uspto.gov>. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free).

Vincent Q. Nguyen  
Primary Examiner  
Art Unit 2858

  
December 14, 2004



Page 1 of 2

PTO/SB/08A (10-01)

Approved for use through 10/31/2002. OMB 0651-0031

U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Substitute for Form 1449A/PTO

### INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(use as many sheets as necessary)

### Complete if Known

Serial No. 10718,147  
Filing Date November 20, 2003  
First Named Inventor RAINS, Gerald T., et al.  
Art Unit 2858  
Examiner Name *nlr V.N*  
Attorney Docket Number P05388US1

Sheet

1 OF 2

### U.S. PATENT DOCUMENTS

*class/subclass*

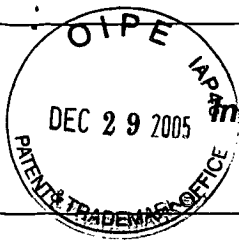
Examiner Initials*	Cite No.(1)	Document Number Number- Kind Code (if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
<i>V.N</i>	1	2,665,409	1/5/1954	ROGERS	<i>324/670</i>
	2	2,788,487	4/09/1957	GROGG, JR.	<i>222/105</i>
	3	3,482,162	12/2/1969	WOCHNOWSKI	<i>324/664</i>
	4	3,760,267	9/18/1973	WILLIAMS	<i>324/670</i>
	5	4,547,725	10/15/1985	OETIKER, ET AL.	<i>324/665</i>
	6	4,599,809	7/15/1986	PARKES	<i>341/484</i>
	7	4,853,614	8/1/1989	CARVER	<i>324/664</i>
	8	5,343,761	9/6/1994	MYERS	<i>73/861.73</i>
	9	6,155,103	12/5/2000	DIEKHANS, ET AL.	<i>73/73</i>
	10	6,285,198	9/4/2001	NELSON, ET AL.	<i>324/664</i>
	11	3,826,979	7/1974	STEINMANN	<i>361/1178</i>
	12	4,896,795	1/1990	EDIGER, ET AL.	<i>222/63</i>
	13	6,121,782	9/2000	ADAMS, ET AL.	<i>324/689</i>
	14	6,388,453	5/2002	GREER	<i>324/667</i>
<i>V.N</i>	15	5,092,819	3/3/1992	SCHROEDER, ET AL.	<i>460/7</i>
	16	5,957,773	9/28/1999	OLMSTED, ET AL.	<i>460/7</i>

### FOREIGN PATENT DOCUMENTS

Examiner	Cite	Foreign Patent Document	Publication Date	Name of Patentee or	Pages, Columns, Lines Where Relevant Passages
Initials*	No.(1)	Country Code(3)- Number(4)- Kind Code(5) (if known)	MM-DD-YYYY	Applicant of Cited Document	or Relevant Passages or Relevant Figures Appear.
<i>V.N</i>	1 GB 2 087 704 A		6/2/1982	CLAYDON, ET AL.	
	2 CA 2,182,989		8/8/1996	NELSON, ET AL.	
	3 EP 0 389 320		9/26/1990	NELSON, ET AL.	
<i>V.N</i>	4 EO 1072 885 A2		6/23/2000	RODE, ET AL.	
	5				
	6				
	7				
	8				
	9				

Examiner Signature	<i>V. Nguyen</i>	Date Considered	<i>12/2004</i>
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## Interview Summary

Application No.

10/718,147

Applicant(s)

RAINS ET AL.

Examiner

Vincent Q Nguyen

Art Unit

2858

All participants (applicant, applicant's representative, PTO personnel):

(1) Vincent Q Nguyen.

(3) \_\_\_\_\_.

(2) Timothy J. Zarley.

(4) \_\_\_\_\_.

Date of Interview: 13 December 2004.

Type: a) ☒ Telephonic b) ☐ Video Conference  
c) ☐ Personal [copy given to: 1) ☐ applicant 2) ☐ applicant's representative]

Exhibit shown or demonstration conducted: d) ☐ Yes e) ☐ No.

If Yes, brief description: \_\_\_\_\_.

Claim(s) discussed: 13-32.

Identification of prior art discussed: \_\_\_\_\_.

Agreement with respect to the claims f) ☐ was reached. g) ☐ was not reached. h) ☒ N/A.

Substance of Interview including description of the general nature of what was agreed to if an agreement was reached, or any other comments: See Continuation Sheet.

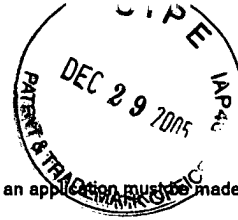
(A fuller description, if necessary, and a copy of the amendments which the examiner agreed would render the claims allowable, if available, must be attached. Also, where no copy of the amendments that would render the claims allowable is available, a summary thereof must be attached.)

THE FORMAL WRITTEN REPLY TO THE LAST OFFICE ACTION MUST INCLUDE THE SUBSTANCE OF THE INTERVIEW. (See MPEP Section 713.04). If a reply to the last Office action has already been filed, APPLICANT IS GIVEN ONE MONTH FROM THIS INTERVIEW DATE, OR THE MAILING DATE OF THIS INTERVIEW SUMMARY FORM, WHICHEVER IS LATER, TO FILE A STATEMENT OF THE SUBSTANCE OF THE INTERVIEW. See Summary of Record of Interview requirements on reverse side or on attached sheet.

Examiner Note: You must sign this form unless it is an Attachment to a signed Office action.

V. Nguyen 12/14/04  
Examiner's signature, if required

## Summary of Record of Interview Requirements



### Manual of Patent Examining Procedure (MPEP), Section 713.04, Substance of Interview Must be Made of Record

A complete written statement as to the substance of any face-to-face, video conference, or telephone interview with regard to an application must be made of record in the application whether or not an agreement with the examiner was reached at the interview.

#### Title 37 Code of Federal Regulations (CFR) § 1.133 Interviews Paragraph (b)

In every instance where reconsideration is requested in view of an interview with an examiner, a complete written statement of the reasons presented at the interview as warranting favorable action must be filed by the applicant. An interview does not remove the necessity for reply to Office action as specified in §§ 1.111, 1.135. (35 U.S.C. 132)

#### 37 CFR §1.2 Business to be transacted in writing.

All business with the Patent or Trademark Office should be transacted in writing. The personal attendance of applicants or their attorneys or agents at the Patent and Trademark Office is unnecessary. The action of the Patent and Trademark Office will be based exclusively on the written record in the Office. No attention will be paid to any alleged oral promise, stipulation, or understanding in relation to which there is disagreement or doubt.

The action of the Patent and Trademark Office cannot be based exclusively on the written record in the Office if that record is itself incomplete through the failure to record the substance of interviews.

It is the responsibility of the applicant or the attorney or agent to make the substance of an interview of record in the application file, unless the examiner indicates he or she will do so. It is the examiner's responsibility to see that such a record is made and to correct material inaccuracies which bear directly on the question of patentability.

Examiners must complete an Interview Summary Form for each interview held where a matter of substance has been discussed during the interview by checking the appropriate boxes and filling in the blanks. Discussions regarding only procedural matters, directed solely to restriction requirements for which interview recordation is otherwise provided for in Section 812.01 of the Manual of Patent Examining Procedure, or pointing out typographical errors or unreadable script in Office actions or the like, are excluded from the interview recordation procedures below. Where the substance of an interview is completely recorded in an Examiners Amendment, no separate Interview Summary Record is required.

The Interview Summary Form shall be given an appropriate Paper No., placed in the right hand portion of the file, and listed on the "Contents" section of the file wrapper. In a personal interview, a duplicate of the Form is given to the applicant (or attorney or agent) at the conclusion of the interview. In the case of a telephone or video-conference interview, the copy is mailed to the applicant's correspondence address either with or prior to the next official communication. If additional correspondence from the examiner is not likely before an allowance or if other circumstances dictate, the Form should be mailed promptly after the interview rather than with the next official communication.

The Form provides for recordation of the following information:

- Application Number (Series Code and Serial Number)
- Name of applicant
- Name of examiner
- Date of interview
- Type of interview (telephonic, video-conference, or personal)
- Name of participant(s) (applicant, attorney or agent, examiner, other PTO personnel, etc.)
- An indication whether or not an exhibit was shown or a demonstration conducted
- An identification of the specific prior art discussed
- An indication whether an agreement was reached and if so, a description of the general nature of the agreement (may be by attachment of a copy of amendments or claims agreed as being allowable). Note: Agreement as to allowability is tentative and does not restrict further action by the examiner to the contrary.
- The signature of the examiner who conducted the interview (if Form is not an attachment to a signed Office action)

It is desirable that the examiner orally remind the applicant of his or her obligation to record the substance of the interview of each case. It should be noted, however, that the Interview Summary Form will not normally be considered a complete and proper recordation of the interview unless it includes, or is supplemented by the applicant or the examiner to include, all of the applicable items required below concerning the substance of the interview.

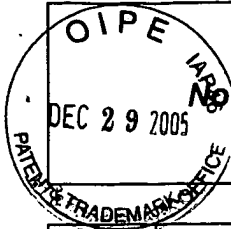
A complete and proper recordation of the substance of any interview should include at least the following applicable items:

- 1) A brief description of the nature of any exhibit shown or any demonstration conducted,
- 2) an identification of the claims discussed,
- 3) an identification of the specific prior art discussed,
- 4) an identification of the principal proposed amendments of a substantive nature discussed, unless these are already described on the Interview Summary Form completed by the Examiner,
- 5) a brief identification of the general thrust of the principal arguments presented to the examiner,  
(The identification of arguments need not be lengthy or elaborate. A verbatim or highly detailed description of the arguments is not required. The identification of the arguments is sufficient if the general nature or thrust of the principal arguments made to the examiner can be understood in the context of the application file. Of course, the applicant may desire to emphasize and fully describe those arguments which he or she feels were or might be persuasive to the examiner.)
- 6) a general indication of any other pertinent matters discussed, and
- 7) if appropriate, the general results or outcome of the interview unless already described in the Interview Summary Form completed by the examiner.

Examiners are expected to carefully review the applicant's record of the substance of an interview. If the record is not complete and accurate, the examiner will give the applicant an extendable one month time period to correct the record.

#### Examiner to Check for Accuracy

If the claims are allowable for other reasons of record, the examiner should send a letter setting forth the examiner's version of the statement attributed to him or her. If the record is complete and accurate, the examiner should place the indication, "Interview Record OK" on the paper recording the substance of the interview along with the date and the examiner's initials.

**Notice of References Cited**

Application/Control No.

10/718,147

Applicant(s)/Patent Under

Reexamination

RAINS ET AL.

Examiner

Vincent Q Nguyen

Art Unit

2858

Page 1 of 1

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	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

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	O					
	P					
	Q					
	R					
	S					
	T					

**NON-PATENT DOCUMENTS**

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

\*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)  
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.



US006917206B2

(12) **United States Patent**  
**Rains et al.**

(10) **Patent No.: US 6,917,206 B2**  
(45) **Date of Patent: Jul. 12, 2005**

(54) **MULTIPLE FREQUENCY GRAIN MOISTURE  
SENSOR FOR COMBINES**

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(\*) Notice: Subject to any disclaimer, the term of this  
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U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/718,147**

(22) Filed: **Nov. 20, 2003**

(65) **Prior Publication Data**

US 2004/0100285 A1 May 27, 2004

**Related U.S. Application Data**

(62) Division of application No. 10/003,884, filed on Oct. 25,  
2001, now Pat. No. 6,686,749.

(51) Int. Cl.<sup>7</sup> ..... **G01R 27/26**

(52) U.S. Cl. .... **324/664; 324/667**

(58) Field of Search ..... **324/664, 667,**  
**324/670, 689, 640, 643; 73/73, 861.73**

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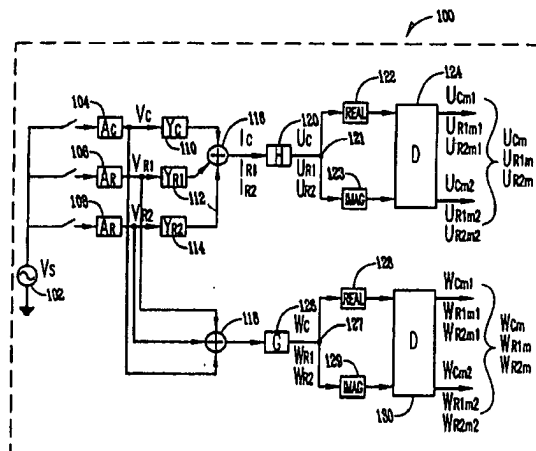
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*Primary Examiner*—Vincent Q. Nguyen

(57) **ABSTRACT**

A grain moisture sensor having a sensor cell that includes a driven plate, a sense plate proximate to and substantially parallel with the driven plate for capacitive measurement across a spacing between the driven plate and the sense plate, and a fill plate adjacent the sense plate and substantially parallel with the driven plate for sensing whether the spacing is filled with grain. The grain moisture sensor provides for measuring real and imaginary components of an excitation voltage applied to the driven plate, measuring real and imaginary components of a sense current sensed at the sense plate, calculating a complex admittance of the cell, calculating a complex admittance of a reference admittance, and calculating a grain complex permittivity.

**15 Claims, 8 Drawing Sheets**



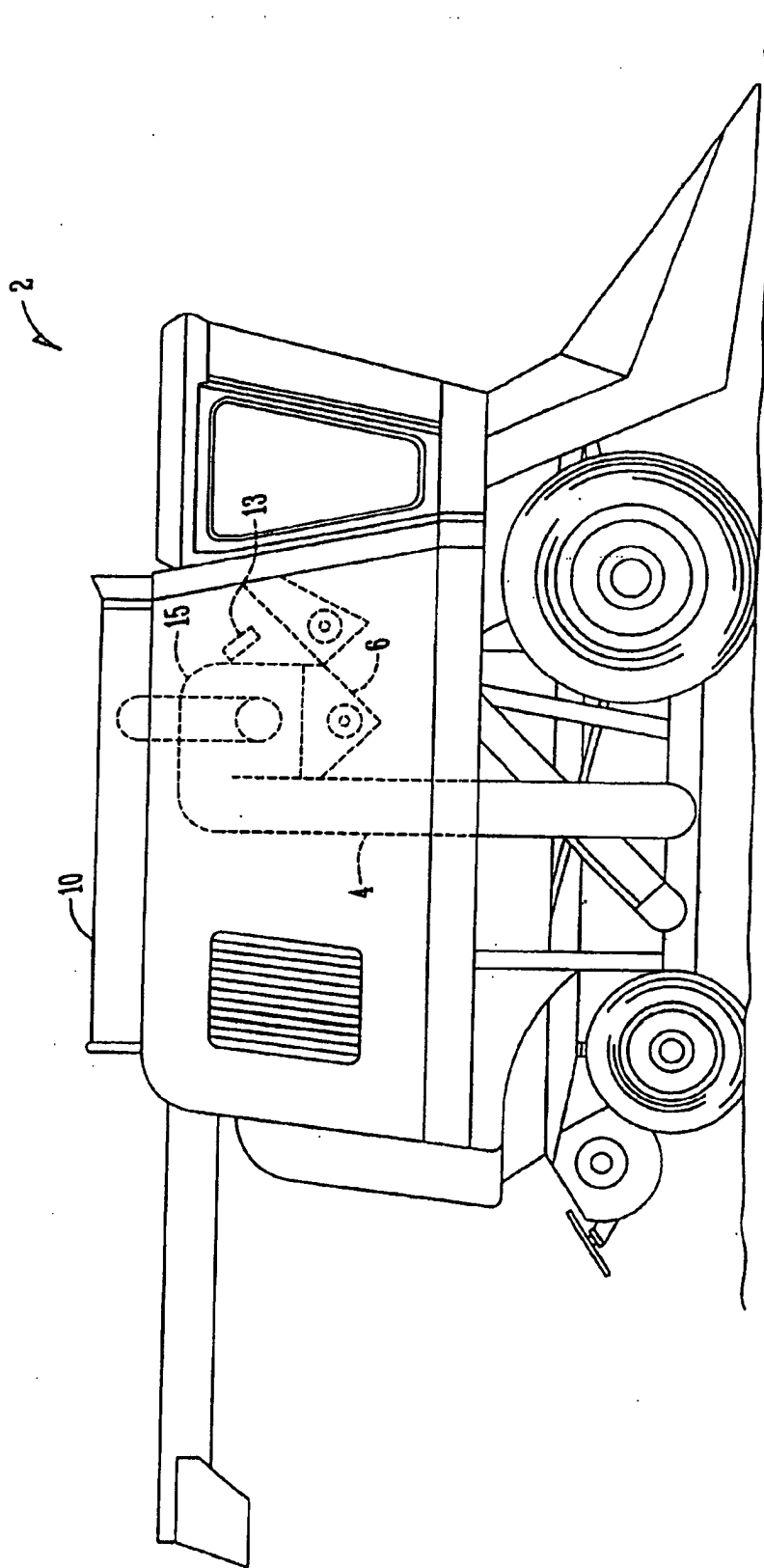
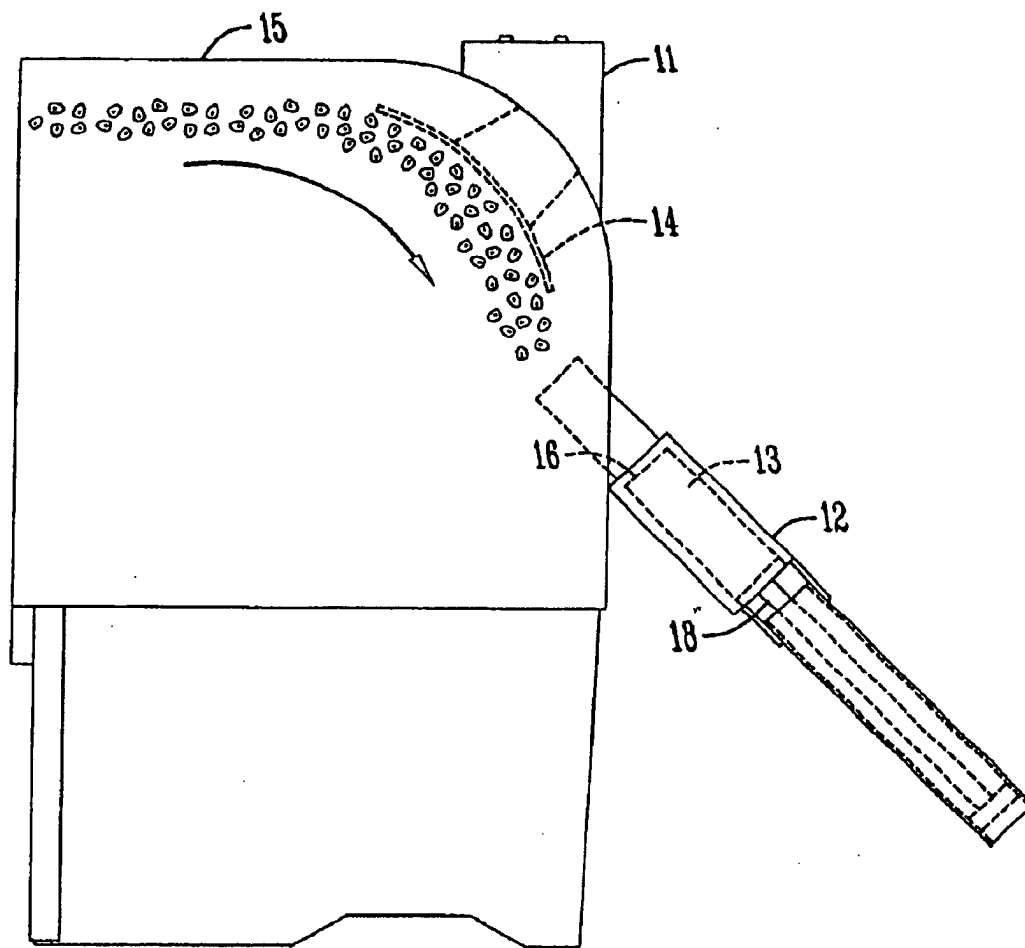
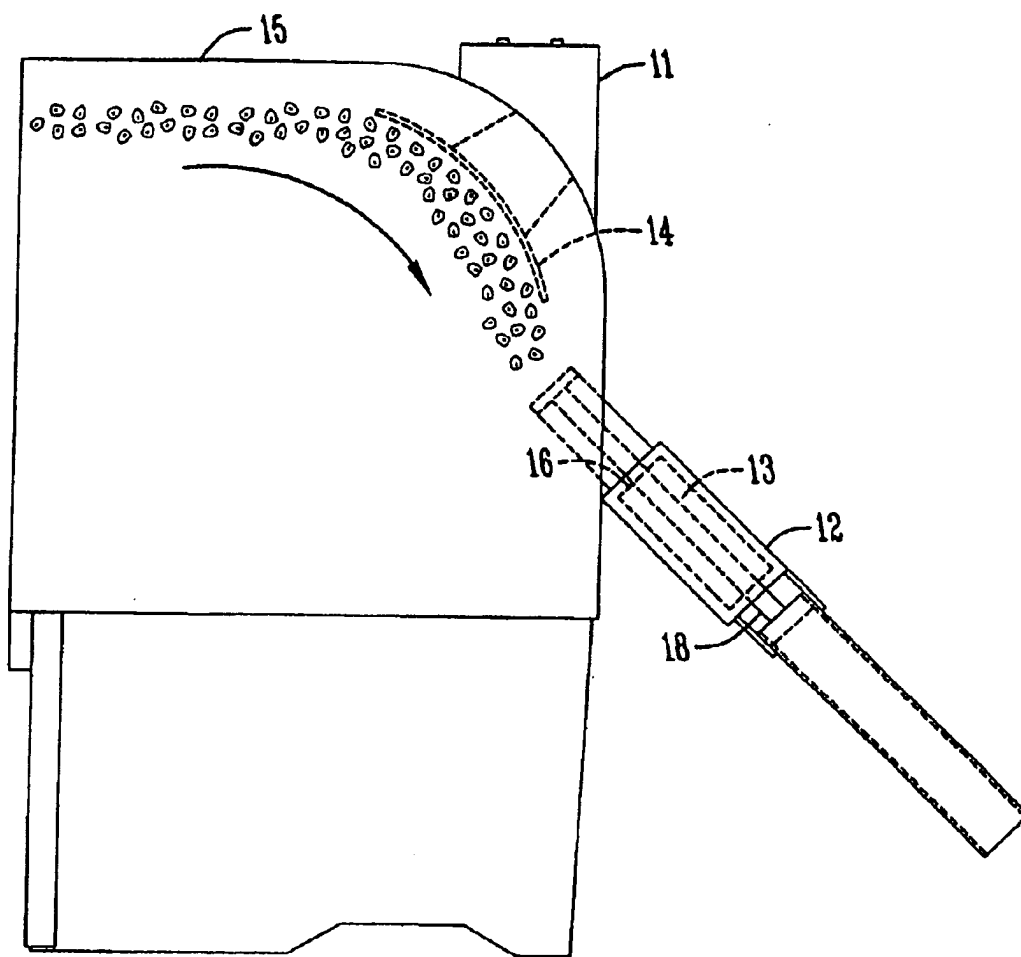


Fig. 1A



*Fig. 1B*



*Fig. 1C*

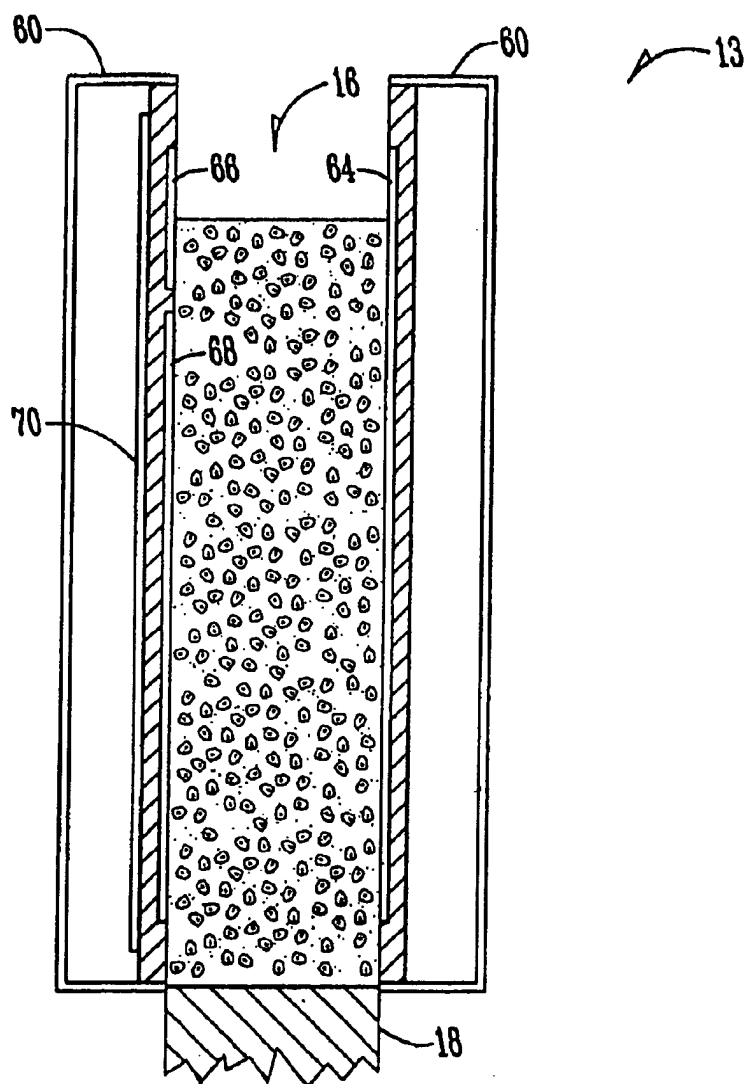
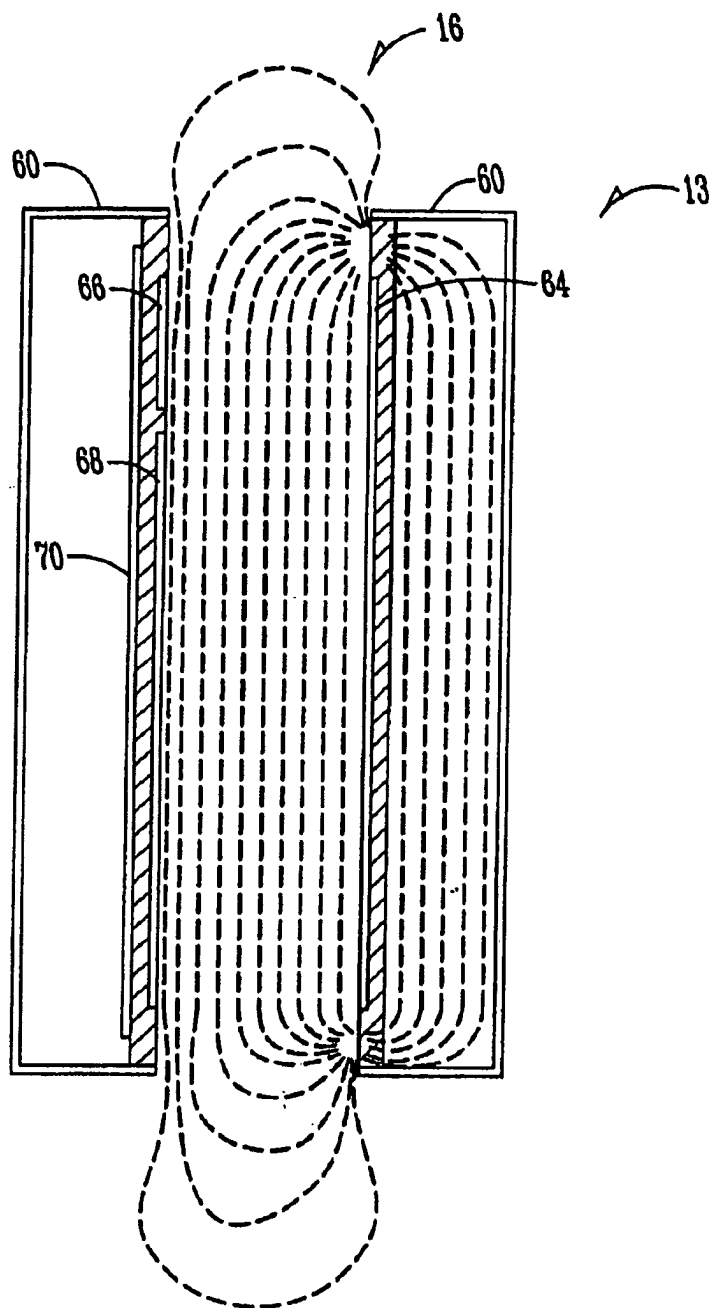


Fig. 2



*Fig. 3*

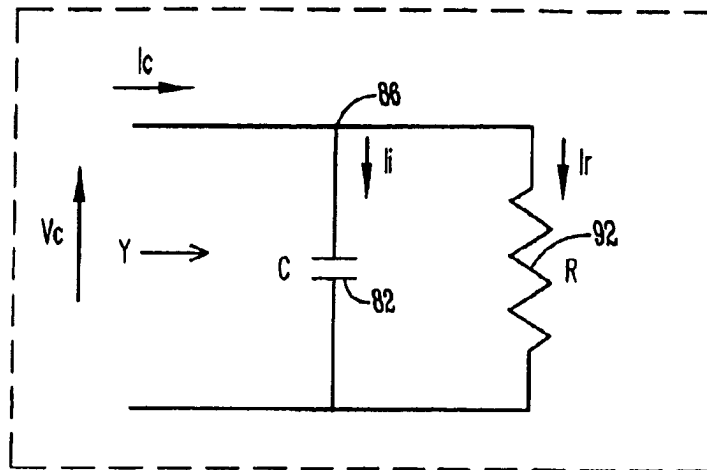


Fig. 4

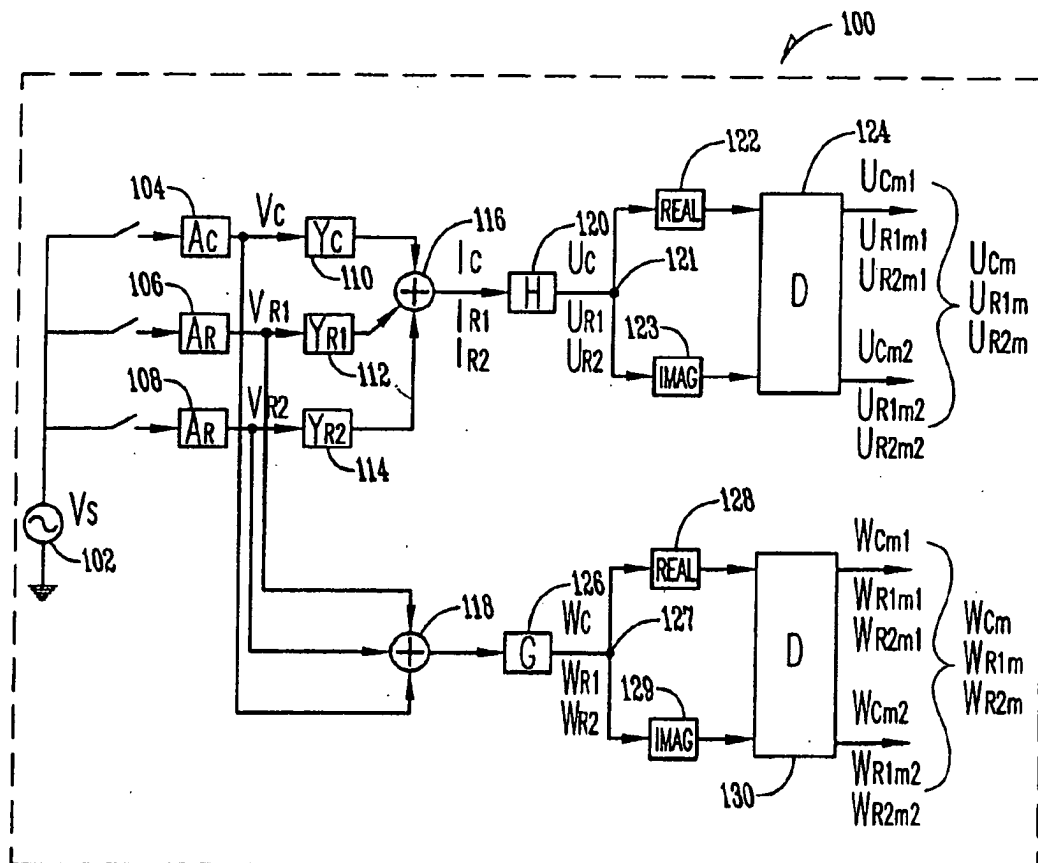
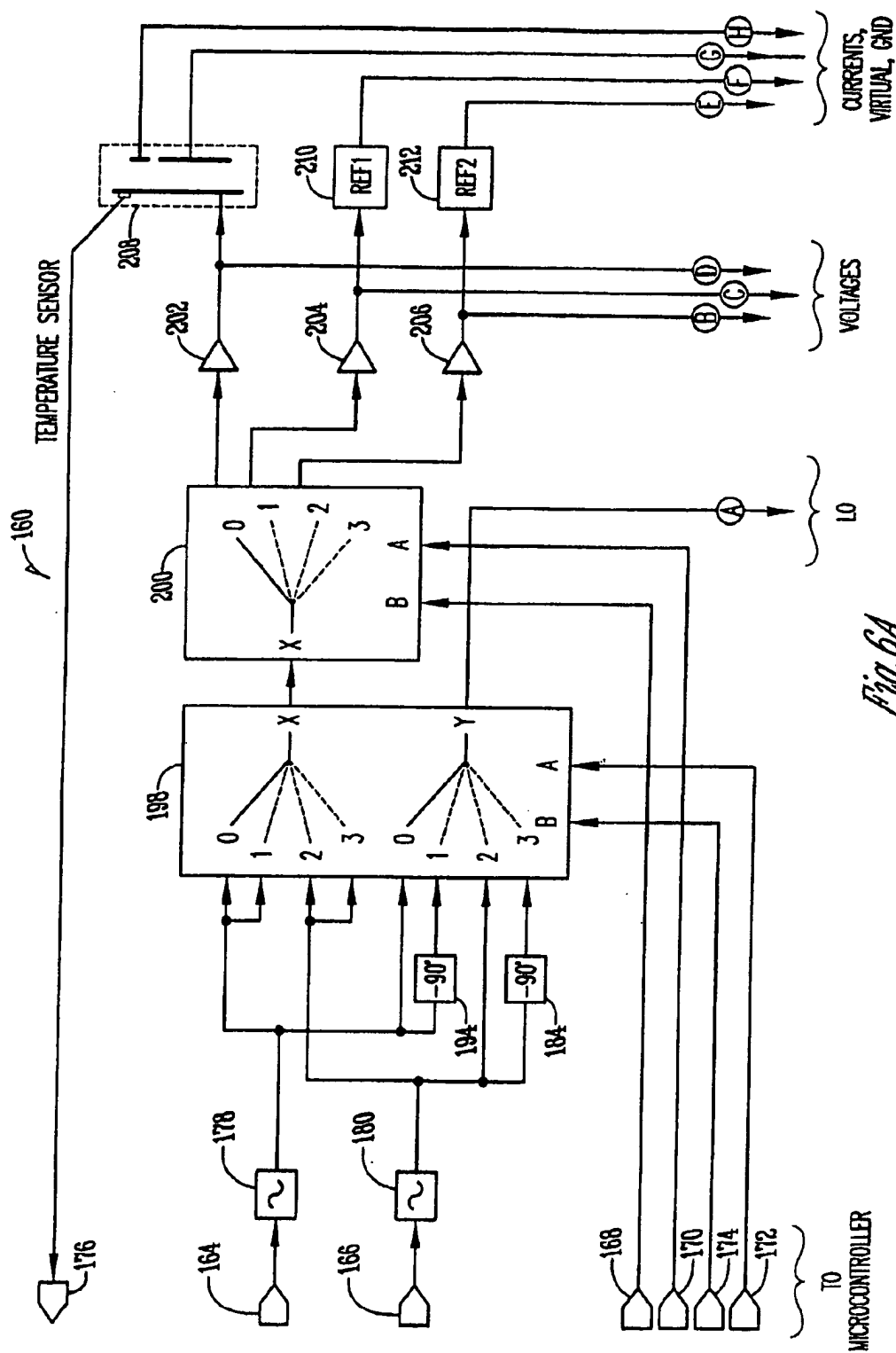
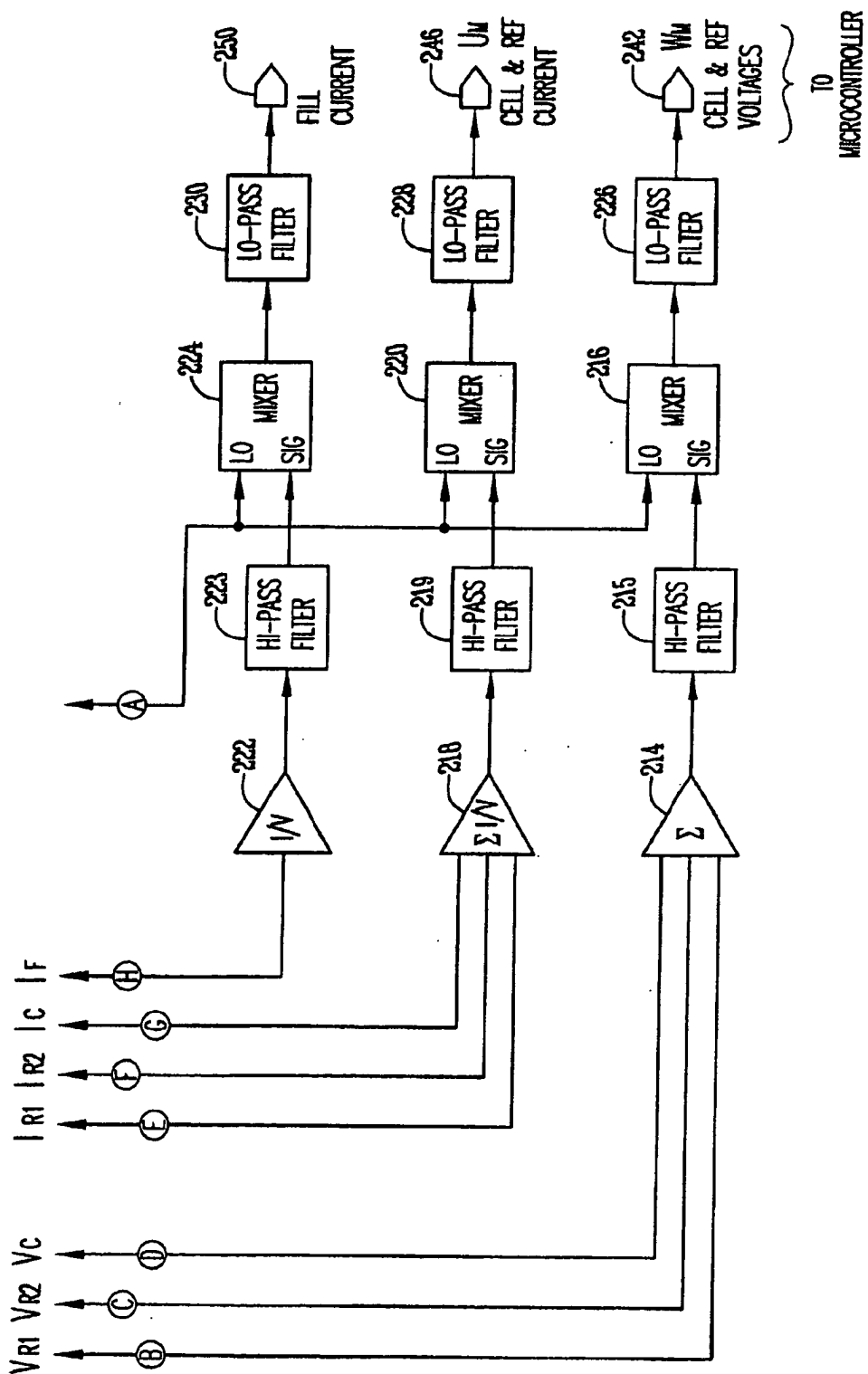


Fig. 5





# **MULTIPLE FREQUENCY GRAIN MOISTURE SENSOR FOR COMBINES**

## **CROSS REFERENCE TO A RELATED APPLICATION**

This application is a division of U.S. Ser. No. 10/003,884 filed Oct. 25, 2001 now U.S. Pat. No. 6,686,749.

## **BACKGROUND OF THE INVENTION**

### **1) Field of the Invention**

The present invention relates generally to grain moisture sensors. More specifically, the present invention relates to an improved grain moisture sensor for combines.

### **2) Related Art**

Grain moisture sensors have been used in combines, particularly in precision agriculture applications. Continuous or instantaneous grain moisture readings allow an operator to observe the moisture of the grain as it is being harvested. In conjunction with a GPS unit, a moisture sensor can be used to provide moisture mapping. In addition, moisture sensors are used in yield monitoring applications. When used in combination with a grain flow sensor, the moisture sensor information is often used to calculate the number of dry bushels in a field and the number of bushels per acre based on the number of wet bushels and the moisture content.

Moisture sensors in combines are commonly mounted in one of two places. The first of these places is in the grain tank auger. The grain tank auger is also known as the loading auger in a combine. There are a number of problems with mounting the moisture sensor in this location. The first is that in order to mount the moisture sensor the fighting of the loading auger must be removed. With removed fighting, material can build up which requires the operator to clean the sensor. If the moisture sensor is not kept clean, readings may be inaccurate or the moisture sensor may be inoperable.

A further problem with mounting the moisture sensor in the loading auger of a combine is the lag time or delay encountered when measuring moisture. When the moisture sensor is mounted in the loading auger position, moisture sensor readings are not taken until the grain is actually in the loading auger of the combine. Therefore, grain must travel up the elevator and fill the sump of the transition housing before the auger is able to deliver grain to the sensor and a moisture measurement can be taken. This deficiency frustrates the use of a moisture sensor in precision agriculture applications, making it more difficult to correctly associate a particular field location with a particular grain moisture.

A further problem with mounting grain moisture sensors in a loading auger is that such a moisture system does not provide for determining when there is sufficient grain present for a grain moisture measurement. Grain moisture sensors usually include capacitive plates. The volume between the plates must be covered before an accurate grain moisture measurement can be made. A moisture sensor that is not filled with grain is not accurately measuring the moisture of the grain. Therefore, this inability to know when the capacitive plate is covered can result in erroneous grain moisture measurements.

Another location that has been used to mount grain moisture sensors is on the side of the clean grain elevator. The clean grain elevator mounting location is thought to provide a steadier flow of grain. Further, the clean grain elevator location may avoid causing accelerated wear of the auger assembly and does not obstruct grain flow in the

manner which the loading auger location may. Despite these improvements, a number of problems remain with mounting a moisture sensor on the side of the clean grain elevator in a combine. One problem relates to the slow cycle time of the moisture sensor. In a low flow condition which is not uncommon in grain harvesting, the sensor can be extremely slow to fill. For example, it may take up to four minutes to fill the sensor. Therefore, the number of moisture sensor readings is reduced and the moisture sensor data is insufficient for providing accurate measurements for moisture maps, yield determinations, and other purposes.

A further problem with mounting moisture sensors on the side of the clean grain elevator relates to the sensitivity of this mounting location in the presence of side slopes. It is not uncommon for a combine to be operating on a hill or slope. When the combine is operated on a slope such that the grain flow is directed away from the moisture sensor inlet, it is nearly impossible to fill the grain moisture sensor with sufficient grain to make a moisture determination.

A further problem with mounting moisture sensors on the clean grain elevator relates to grain leaks. When mounted on the side of the clean grain elevator, any grain leaks that occur result in the leaking grain spilling on the ground, as the grain leaks are not contained.

Another problem in grain moisture sensing relates to the sensor cell. Typically, the sensor cell consists of a parallel plate capacitor in which the grain serves as the dielectric material. The cell capacitance and therefore the permittivity of the grain between the plates is measured. From this measurement, the moisture of the grain is determined. Normally, these cell designs are not as close to an ideal parallel plate capacitor as desired. In particular, prior art designs for grain moisture sensors for use in combines use cells that are subject to electric field fringe effects. A fringe effect occurs when electric field lines are not both straight and perpendicular to the plates of the parallel plate capacitor. These fringe effects produce an uncontrollable influence on the measurements from material other than grain that is close to the cell but outside of the cell. Another problem with cell designs is that they do not produce uniformly dense electric field lines between the parallel plates. The nonuniform electric field density creates the problem of unequal sensitivity to grain throughout the cell. Thus the measurements of the moisture of the grain within the cell are not as accurate as desired in these respects.

Another problem relating to the prior art relates to the method for measuring cell capacitance. Measuring the capacitance of a cell filled with grain is a traditional way of obtaining grain moisture. There are two common prior art methods for measuring cell capacitance. The first method is to sense the changes in frequency of a variable oscillator that uses cell capacitance as one of its frequency determining elements. The second method is to excite the cell capacitance with a signal having a known frequency and to measure the absolute value of the resulting cell current, usually with a bridge type of circuit and a peak detector, and then to calculate the capacitance of the cell. Both of these methods tend to be dependent on grain cell construction and are sensitive to noise, changes in circuit characteristics, and parasitic effects. The first method also has the problem of poor control of frequency, especially as moisture varies. Both of these methods are also single dimensional, lacking the ability to measure both the dielectric and the loss properties of the grain. Therefore numerous problems remain with this type of sensing.

The combination of the dielectric and loss parameters is known as the complex permittivity. Complex permittivity is

an intrinsic, frequency dependent material property. The knowledge of the grain's complex permittivity at more than one frequency has been found to be a part of advanced moisture level assessment as has been demonstrated by USDA studies. Despite this observation, problems remain.

#### BRIEF SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a grain moisture sensor for use on a combine that improves upon the state of the art.

It is another object of the present invention to provide a grain moisture sensor that provides accurate and consistent grain moisture measurements.

It is a further object of the present invention to provide a grain moisture sensor that does not require the removal of flighting in the loading auger for cleaning.

Yet another object of the present invention is to provide a grain moisture sensor that avoids lags in time between when grain is harvested and when the moisture measurement is taken.

A further object of the present invention is to provide a grain moisture sensor that is capable of determining when the sensor cell is full.

Yet another object of the present invention is to provide an improved grain moisture sensor that is less affected by low flow conditions.

Yet another object of the present invention is to provide a grain moisture sensor for use in a combine that is insensitive to changes in the side slope of the ground being harvested.

Yet another object of the present invention is to provide a grain moisture sensor that contains grain leaks.

A still further object of the present invention is to provide a grain moisture sensor with a cell that has characteristics closer to an ideal parallel plate capacitor.

A still further object of the present invention is to provide a grain moisture sensor that provides for uniform electric field density to allow for equal sensitivity to grain throughout the cell.

Yet another object of the present invention is to provide a grain moisture sensor with a cell for reducing fringe effects produced by material other than grain that may be close to, but outside of the cell.

Yet another object of the present invention is to provide a grain moisture sensor that provides for increased protection from electromagnetic interference.

A still further object of the present invention is to provide a grain moisture sensor that provides for the measurement of complex permittivity of the grain.

Another object of the present invention is to provide a grain moisture sensor that provides for the measurement of complex permittivity of the grain at more than one frequency.

A grain moisture sensor of the present invention provides for the sensing of the moisture of grain being harvested by a combine. One aspect of the present invention relates to the location of the grain moisture sensor on the combine. According to the present invention, the grain moisture sensor is mounted off of the front of the clean grain elevator transition housing inside of the grain tank. This provides the advantages of access to the grain moisture sensor if required and the advantage that all leaks are contained. A further advantage is that the grain moisture sensor fills positively with grain. Further, this location of the grain moisture sensor allows for the sensor to always be filled regardless of the slope conditions of the combine.

Another aspect of the present invention relates to the cell design of the sensor. The cell of the present invention includes a driven plate to which excitation voltages are applied, a sense plate proximate and parallel to the driven plate for measuring current that passes through the cell, a fill plate adjacent to the sense plate for determining when the cell is full, and a guard adjacent to the sense plate and the fill plate for protecting the sense plate and the fill plate. The guard is electrically isolated from, but at the same potential as a sensed plate. The guard is parallel to and dimensionally larger than the sense plate in order to shape the electric field. The presence of the guard plate provides the advantage of straight electric field lines perpendicular to the sense plate and of uniform density throughout the region between the parallel plates. This results in reduced fringe effects and uniform electric field density allowing for equal sensitivity to grain throughout the cell. In addition, the guard shields the sense plate from external electric fields generated by sources other than the driven plate. The fill plate provides the advantage of accurate determination of whether or not the cell is full.

A further aspect of the present invention is the method in which the capacitance of a cell filled with grain is measured. The present invention provides for measurement of the complex permittivity of the grain. Further, the present invention provides for measurement of the complex permittivity at more than one frequency. This provides the advantage of permitting compensation for variations in grain density and conductivity effects which is particularly important in mobile moisture sensing applications such as the use of a moisture sensor on a combine. According to this aspect of the present invention, the circuit measures the real and imaginary components of both the excitation voltage and the sense current. From these values, the complex admittance of the cell is calculated. The measurements are repeated for the empty cell and the cell filled with grain. When the empty cell is not available, the calibrated reference admittances are used instead. The grain complex permittivity can then be calculated from these measurements. Mixers are used in the measurement of real and imaginary components of the voltage and current. This synchronous detection method has a very narrow band filtering effect, greatly reducing noise influence on the measurement. A virtual ground method of measuring low-level currents is used to provide the advantage of a substantial reduction in the influence of parasitic elements at the current sensing node. In addition, measurements can be corrected with the calibrated references to compensate for any environmental changes that may influence the circuit characteristics. This provides the advantage of securing stable and repetitive results.

In this matter, the present invention provides advantages in an improved grain moisture sensor.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a side view that shows a combine with a grain moisture sensor according to the present invention.

FIG. 1B is a side view of the grain moisture sensor of the present invention mounted in a combine and in a fill position.

FIG. 1C is a side view of the grain moisture sensor of the present invention mounted in a combine in a sensing position.

FIG. 2 is a side cross section of the cell of the grain moisture sensor of the present invention.

FIG. 3 is a side cross section of the cell of FIG. 2 showing the equipotential lines of the electric field that is created

when an excitation voltage is applied to the driven plate of the present invention.

FIG. 4 is a circuit schematic of a model for the capacitor cell according to the present invention.

FIG. 5 is a block diagram of the admittance measuring circuit according to the grain moisture sensor of the present invention.

FIGS. 6A and 6B are block diagrams of the moisture sensor circuit according to the present invention.

#### DETAILED DESCRIPTION OF THE INVENTION

FIG. 1A shows a combine having a grain moisture sensor according to the present invention. In FIG. 1A, the combine 2 is shown with a grain tank 10. In addition, the clean grain elevator 4 is shown. Grain from the clean grain elevator 4 travels to the transition housing 15 of the grain tank 10. The sump 6 of the transition housing is also shown.

FIGS. 1B and 1C show side views of the grain moisture sensor of the present invention as mounted in a combine. The grain tank 10 shown includes the grain moisture sensor 12. The grain moisture sensor 12 is located in the grain tank 10 of the combine near the mass flow sensor 11. The cell opening 16 is located below the impact plate 14 in the transition housing 15. Although an impact plate 14 is shown, the present invention contemplates that other deflectors can be used. In this location, the cell 13 is positively filled due to the direct or indirect velocities of grain created from the clean grain elevator paddles (not shown). This permits the cell 13 to be filled at high rates. This reduces any problems with slow cycle times associated with low flow conditions as here, the cell 13 is filled at a high rate due to its placement within the stream of grain created by the clean grain elevator. The cell 13 is placed in line with the cell inlet. A plunger/piston 18 with an electric actuator is used to force the grain sample back out of the inlet opening. In FIG. 1C, the cell 13 and plunger/piston 18 are in a sensing position.

FIG. 2 illustrates a side view of the cell 13 of the present invention. The cell opening 16 or spacing is filled with grain. On either side of the spacing are parallel capacitor plates 64 and 68. The driven plate 64 is the plate to which an excitation voltage is applied. The sense plate 68 is the plate at which current is measured passing through the cell. The fill plate 66 is adjacent to the sense plate 68 and parallel to the driven plate 64.

The fill sensor plate is one-fourth the size of the sense plate. To determine when the cell is full, the fill plate should indicate a measured reading of one-fourth the sense plate measured reading. Although in this embodiment the fill sensor is one-fourth the size of the sense plate, the present invention contemplates numerous variations in the sizes of the plates. This is merely one example of a relative size which is convenient and useful.

The guard 70 is strategically placed behind the sense plate 68 and the fill plate 66. The guard 70 is parallel to and dimensionally larger than the sense plate 68 in order to shape the electric field. In addition, the guard 70 also shields the sense plate from external electric fields generated by sources other than the driven plate 64.

FIG. 3 illustrates the cell of the moisture sensor with the equipotential lines of the electric field that is generated when an excitation signal is applied to the driven plate 64. Due to the placement of the shield or guard 70, which is electrically isolated from but at the same potential as the sense plate 68, the effect on the electric field lines in the vicinity of the sense

plate is to produce the equivalent of an ideal parallel plate capacitor without fringe effects. The electric field lines are straight in nature and perpendicular to the sense and fill plates. Further, the electric field lines are uniform in density throughout the region between the parallel plates. The result is that fringe effects are reduced. Fringe effects produce uncontrollable influence on the measurements from material other than the grain that are close to but outside of the cell. Here, the straight electric field lines within the cell show that the cell is largely immune from that influence. Further, the uniform electric field density provides for equal sensitivity to grain throughout the entire cell. In addition, the entire cell and the electronics are contained in a metal enclosure 60. The metal enclosure 60 serves as an electromagnetic interference shield, further isolating the entire cell from other sources of electromagnetic energy.

The present invention provides for grain moisture calculations based on the measurement of the complex relative permittivity of the grain (henceforth referred to as "complex permittivity"). FIG. 4 illustrates a schematic diagram of a circuit that is electrically equivalent to the capacitor cell of the present invention. This equivalent circuit includes an ideal capacitor 82 having a value of C in parallel with an ideal resistor 92 having a value of R. The ideal capacitor 82 represents the capacitive or energy storing property of the cell and the ideal resistor 92 represents the conductive or energy dissipating property of the cell. C and R are dependent on the frequency of excitation and on the moisture, temperature, and certain other properties of the grain.

The complex admittance of the cell is

$$Y = \frac{1}{R} + j \cdot \omega \cdot C$$

where

$\omega = 2 \cdot \pi \cdot f$

f = frequency of excitation

j = the imaginary unit

When the cell is empty it has essentially no energy dissipating properties. Its admittance is very close to that of an ideal capacitor having a value of  $C_{CE}$ :

$$Y_{CE} = j \cdot \omega \cdot C_{CE}$$

When the cell is filled with grain it has both energy dissipating and energy storing properties. Its admittance is

$$Y_{CF} = \frac{1}{R_{CF}} + j \cdot \omega \cdot C_{CF}$$

Dividing the filled cell admittance by the empty cell admittance gives

$$\begin{aligned} \frac{Y_{CF}}{Y_{CE}} &= \frac{\frac{1}{R_{CF}} + j \cdot \omega \cdot C_{CF}}{j \cdot \omega \cdot C_{CE}} \\ &= \frac{\frac{1}{R_{CF}}}{j \cdot \omega \cdot C_{CE}} + \frac{C_{CF}}{C_{CE}} \\ &= \frac{C_{CF}}{C_{CE}} - j \cdot \frac{1}{\omega \cdot C_{CE} \cdot R_{CF}} = \epsilon \end{aligned}$$

This ratio is the complex permittivity of the grain. Complex permittivity is an intrinsic material property, dependent only on the frequency of excitation and on the moisture,

temperature, and certain other properties of the grain. It is independent of the dimensions and shape of the cell. Complex permittivity is commonly written as follows:

$$\epsilon = \epsilon' - j\epsilon''$$

where

$\epsilon'$  = dielectric constant

$\epsilon''$  = loss factor

It is an objective of the circuitry of the present invention to measure the empty cell admittance and the full cell admittance in order to use the above equations to compute the complex permittivity of the grain. As shown on FIG. 4, the complex excitation voltage,  $V_C$ , is applied across the circuit. The resulting complex current,  $I_C$ , flows through the circuit.  $V_C$  has real component  $V_r$  and imaginary component  $V_i$ .

$$V_C = V_r + jV_i$$

$I_C$  has real component  $I_r$  and imaginary component  $I_i$ :

$$I_C = I_r + jI_i$$

By measuring  $V_r$ ,  $V_i$ ,  $I_r$ , and  $I_i$ , the complex admittance  $Y$  can be calculated using complex arithmetic:

$$Y = \frac{I_C}{V_C} = \frac{I_r + jI_i}{V_r + jV_i}$$

FIG. 5 illustrates the admittance measuring circuit used in the grain moisture sensor according to the present invention. In FIG. 5, the admittance measuring circuit 100 is shown. For explanation purposes, the following definitions are used:  $U_{R1m}$  is defined as the measured value of  $U_{R1}$  defined below.  $U_{R1m1}$  is the real part (in phase signal value) of  $U_{R1m}$ .  $U_{R1m2}$  is the imaginary part (quadrature signal value) of  $U_{R1m}$ .  $U_{R2m}$  is defined as the measured value of  $U_{R2}$  defined below.  $U_{R2m1}$  is the real part (in phase signal value) of  $U_{R2m}$ .  $U_{R2m2}$  is the imaginary part (quadrature signal value) of  $U_{R2m}$ .  $U_{Cm}$  is defined as the measured value of  $U_C$  defined below.  $U_{Cm1}$  is the real part (in phase signal value) of  $U_{Cm}$ .  $U_{Cm2}$  is the imaginary part (quadrature signal value) of  $U_{Cm}$ .  $W_{R1m}$  is defined as the measured value of  $W_{R1}$  defined below.  $W_{R1m1}$  is the real part (in phase signal value) of  $W_{R1m}$ .  $W_{R1m2}$  is the imaginary part (quadrature signal value) of  $W_{R1m}$ .  $W_{R2m}$  is defined as the measured value of  $W_{R2}$  defined below.  $W_{R2m1}$  is the real part (in phase signal value) of  $W_{R2m}$ .  $W_{R2m2}$  is the imaginary part (quadrature signal value) of  $W_{R2m}$ .  $W_{Cm}$  is defined as the measured value of  $W_C$  defined below.  $W_{Cm1}$  is the real part (in phase signal value) of  $W_{Cm}$ .  $W_{Cm2}$  is the imaginary part (quadrature signal value) of  $W_{Cm}$ .  $U_C$  is defined as a complex voltage value that represents the current passing through the cell.  $U_{R1}$  is defined as a complex voltage value that represents the current passing through the first reference.  $U_{R2}$  is defined as a complex voltage value that represents the current passing through the second reference.  $W_C$  is defined as a complex voltage value that represents the voltage across the cell.  $W_{R1}$  is defined as a complex voltage value that represents the voltage across the first reference.

$W_{R2}$  is defined as a complex voltage value that represents the voltage across the second reference.

$I_C$  is the complex current passing through the cell.

$I_{R1}$  is the complex current passing through the first reference.

$I_{R2}$  is the complex current passing throughout the second reference.

$V_C$  is the complex voltage across the cell.

$V_{R1}$  is the complex voltage across the first reference.

$V_{R2}$  is the complex voltage across the second reference.

$Y_C$  is the complex admittance of the cell.

$Y_{R1}$  is the complex admittance of the first reference.

$Y_{R2}$  is the complex admittance of the second reference.

$H$  is the transfer function of the circuitry that performs complex current measurements.

$G$  is the transfer function of the circuitry that performs complex voltage measurements.

$V_S$  is the generated source voltage.

$A_C$  is the transfer function for cell drive voltage.

$A_R$  is the transfer function for reference drive voltage.

$D$  is the transfer function of the phase and gain mismatch between the measured real (in-phase) and measured imaginary (quadrature) components of the complex current and voltage. This mismatch is caused by imperfections in the circuit elements that do the measuring.  $D$  is also known as the "mixer transformation matrix". It is an object of the present invention to measure the value of  $D$  and to correct for its influence.

In the admittance measuring circuit 100, a generated source voltage 102 ( $V_S$ ) is selectively applied to the cell or to one of a plurality of references through an associated transfer function as indicated by reference numerals 104, 106, and 108. When  $V_S$  is applied to transfer function  $A_C$  104, a voltage  $V_C$  is produced which is applied to the complex admittance for the cell,  $Y_C$  110. Similarly, when the voltage 102 ( $V_S$ ) is applied to a first transfer function  $A_R$  106 the resulting voltage  $V_{R1}$  is applied to the complex admittance of the first reference admittance,  $Y_{R1}$  112, and when the signal 102 is applied to the second transfer function  $A_R$  108, the resulting voltage  $V_{R2}$  is applied to the second complex admittance 114 ( $Y_{R2}$ ). Each of the resulting currents is summed in an adder 116. Where only one path is selected, only one of these signals will be nonzero. The resulting current is then  $I_C$  if the cell is selected,  $I_{R1}$  if the first reference is selected, and  $I_{R2}$  if the second reference is selected. The resulting current flows through a circuit having transfer function  $H$  120,  $H$  being a transfer function for converting complex current to a complex voltage for measurement purposes. The resulting voltage measured through node 121 represents the complex current through either the cell admittance or one of the reference admittances. The real and imaginary (in-phase and quadrature) components of this voltage are determined by applying the voltage to the subcircuit consisting of blocks 128, 129, and 130 as shown in FIG. 5. Thus in this manner, voltages  $U_{Cm1}$  and  $U_{Cm2}$  representing the complex current through the cell are measured. By selecting either of the references, voltages representing the complex current through the first reference or through the second reference can also be measured.

In addition to measuring voltages that represent the complex current values, voltages that represent the complex voltage values are also calculated according to the circuit. The voltages from the cell,  $V_C$ , the first reference,  $V_{R1}$ , and the second reference,  $V_{R2}$  are applied to an adder 118. As only one of the references or the cell is selected at a time, only one of these values will be non-zero. The result is applied to a transfer function 126 resulting in a complex

voltage at node 127. The real and imaginary (in-phase and quadrature) components of this voltage are determined by applying the voltage to the subcircuit consisting of blocks 128, 129, and 130 as shown in FIG. 5.

In this manner, the circuit shown in FIG. 5 provides for determination of the real and imaginary parts of both the voltage and the current associated with a particular admittance. This admittance being either that associated with the cell of the grain moisture sensor or that associated with one of the reference admittances of the grain moisture sensor.

To further explain, the following mathematical relationships are present:

$$G = \frac{W}{V} \quad H = \frac{U}{I}$$

In each case, the respective transfer functions are defined as the ratio of the output of the function to the input of the function.

In addition, the admittance is defined mathematically as:

$$Y = \frac{I}{V} = \frac{\frac{U}{H}}{\frac{W}{G}} = \frac{U}{W} \cdot \frac{G}{H}$$

Given these general relationships, the admittance of a reference is defined as:

$$Y_R = \frac{U_R}{W_R} \cdot \frac{G}{H}$$

Further, the empty cell admittance, Y<sub>CE</sub>, and a full cell admittance, Y<sub>CF</sub>, are calculated as follows:

$$Y_{CE} = \frac{U_{CE}}{W_{CE}} \cdot \frac{G}{H}$$

$$Y_{CF} = \frac{U_{CF}}{W_{CF}} \cdot \frac{G}{H}$$

If the measurements for the reference admittance and the cell admittance are done in the same environmental conditions, it can be assumed that both G and H are the same in the cell admittance equations and the reference admittance equations. Then the following characterizes the empty cell and reference calibration factor F:

$$\frac{W_R}{U_R} \cdot Y_R = \frac{W_{CE}}{U_{CE}} \cdot Y_{CE} \Rightarrow F = \frac{W_{CE}}{U_{CE}} \cdot \frac{U_R}{W_R} = \frac{Y_R}{Y_{CE}}$$

The reference calibration factor, F, gives the ratio of the reference admittance to the empty cell admittance at the same environmental conditions. Thus a reference admittance can be used instead of an empty cell admittance for calibration purposes.

Assuming that F will stay constant, the sampled grain's complex permittivity can be calculated as:

$$\epsilon = \frac{U_{CF} \cdot W_R}{W_{CF} \cdot U_R} \cdot F$$

Where:

$$\epsilon = \epsilon' - j\epsilon''$$

Thus, the present invention provides for measurement of the complex permittivity of grain for moisture sensing purposes.

To make accurate current and voltage measurements it is necessary that the in-phase (IP) and quadrature (Q) local oscillator signals used with mixers 216, 220, and 224 to extract the real and imaginary components of complex signals have a phase difference of exactly 90 degrees and have identical amplitudes at their fundamental frequencies. Errors will be introduced to the extent that this is not the case. By using two reference admittances of known and stable values however, corrections to these errors are made.

The D functions 124 and 130 represent the distortion of the imaginary part with the respect to the real part of all measured complex values. All measured values  $U_m$  and  $W_m$  can be corrected, using the same formula to obtain U and W, which are the values before any measurement distortion error is introduced.

The following is the distorted relationship between the complex voltages representing cell and reference currents and their measured values:

$$U = [1 \ j] D^{-1} \cdot U_m$$

where:

$$D^{-1} = PFC = \begin{bmatrix} 1 & 0 \\ pfc1 & pfc2 \end{bmatrix}$$

$$U_m = \begin{bmatrix} U_{m1} \\ U_{m2} \end{bmatrix}$$

The same distorted relationship holds between the complex voltages representing cell and reference voltages and their measured values:

$$W = [1 \ j] D^{-1} \cdot W_m$$

where:

$$D^{-1} = PFC = \begin{bmatrix} 1 & 0 \\ pfc1 & pfc2 \end{bmatrix}$$

$$W_m = \begin{bmatrix} W_{m1} \\ W_{m2} \end{bmatrix}$$

Expanding the above equations gives

$$U = U_{m1} + j \cdot (pfc1 \cdot U_{m1} + pfc2 \cdot U_{m2})$$

$$W = W_{m1} + j \cdot (pfc1 \cdot W_{m1} + pfc2 \cdot W_{m2})$$

The pfc1 and pfc2 correction factors are found through the use of two different references having known and stable admittance values of different phase angles. As an example, in one embodiment of the present invention the first reference is a temperature stable 1% capacitor (COG) with a value of 15 pF (admittance  $Y_{R1}$ ) and the second reference is a precision 0.1% resistor with value of 2000  $\Omega$  (admittance  $Y_{R2}$ ). Other reference values may be used as well.

The ratio of the reference admittances is computed as follows, with the example values also shown:

$$R = \frac{Y_{R1}}{Y_{R2}} = Q_R + j \cdot Q_I = 2000 \cdot j \cdot (2\pi \cdot f \cdot 15 \cdot 10^{-12})$$

The ratio of the raw measurements of two references is:

$$Rm = \frac{U_{R1} \cdot W_{R2}}{W_{R1} \cdot U_{R2}}$$

Expanding the above equation to include the measured values results in:

$$Rm = \frac{(U_{R1m1} + j(U_{R1m1} \cdot pfc1 + U_{R1m2} \cdot pfc2)) \cdot (W_{R2m1} + j(W_{R2m1} \cdot pfc1 + W_{R2m2} \cdot pfc2))}{(W_{R1m1} + j(W_{R1m1} \cdot pfc1 + W_{R1m2} \cdot pfc2)) \cdot (U_{R2m1} + j(U_{R2m1} \cdot pfc1 + U_{R2m2} \cdot pfc2))}$$

Rm is set equal to R and two quadratic equations in two unknowns (pfc1, pfc2) are derived:

$$a_1 pfc_1^2 + b_1 pfc_2^2 + c_1 pfc_1 pfc_2 + d_1 pfc_1 + e_1 pfc_2 + f_1 = 0 \text{ (from real part)}$$

$$a_2 pfc_1^2 + b_2 pfc_2^2 + c_2 pfc_1 pfc_2 + d_2 pfc_1 + e_2 pfc_2 + f_2 = 0 \text{ (from imaginary part)}$$

where:

$$a_1 = Q_R \cdot W_{R1m1} \cdot U_{R2m1} - U_{R1m1} \cdot W_{R2m1}$$

$$a_2 = Q_I \cdot W_{R1m1} \cdot U_{R2m1}$$

$$b_1 = Q_R \cdot W_{R1m2} \cdot U_{R2m2} - U_{R1m2} \cdot W_{R2m2}$$

$$b_2 = Q_I \cdot W_{R1m2} \cdot U_{R2m2}$$

$$c_1 = Q_R \cdot W_{R1m1} \cdot U_{R2m2} + Q_R \cdot W_{R1m2} \cdot U_{R2m1} - U_{R1m1} \cdot W_{R2m2} - U_{R1m2} \cdot W_{R2m1}$$

$$c_2 = c_1$$

$$d_1 = 2 \cdot Q_I \cdot W_{R1m1} \cdot U_{R2m1}$$

$$d_2 = -2 \cdot a_1$$

$$e_1 \cdot Q_I \cdot (W_{R1m1} \cdot U_{R2m2} + W_{R1m2} \cdot U_{R2m1})$$

$$e_2 = -c_1$$

$$f_1 = -a_1$$

$$f_2 = -a_2$$

These two quadratic equations are then solved simultaneously for pfc1 and pfc2. As a simple closed form solution is not available, they may be solved by Newton-Raphson iteration for example. Other numerical equation solving algorithms may be used as well. The solution is known to be near the point (pfc1=0, pfc2=1) hence this is preferably used for a starting point. In theory four different solutions are possible. Any solution not near (0,1) shall be considered extraneous. In a software implementation, an appropriate error condition can be set. This is not likely to happen, however, if it does occur, precautions can be taken when the error condition is present.

FIGS. 6A and 6B show a schematic of the grain moisture sensor according to the present invention. The schematic shows a number of input and output lines for connection to an intelligent control such as a processor, microcontroller, integrated circuit, or other device. This schematic shows merely one circuit configuration of the present invention. The present invention provides for the ability to selectively measure one of a plurality of complex admittances at a plurality of frequencies.

The inputs to the system (outputs from an intelligent controller) are shown in FIG. 6A. The inputs include a first frequency input 164 and a second frequency input 166. Optionally a first sine wave generator 178 and a second sine wave generator 180 are used. The sine wave generators take the square wave output of a microcontroller, divide the frequency as necessary, and smooth the output such that a sinusoidal signal is produced. The output from the first sine

wave generator 178 is electrically connected to three switch inputs of dual quad switch 198. In addition, the output from the first sine wave generator 178 is electrically connected to a 90 degree phase shifter 194. The 90 degree phase shifter 194 is constructed such that its output signal is 90 degrees out of phase with its input signal. The 90 degree phase shifter 194 is electrically connected to a switch input of the dual quad input switch 198. The output of the second sine wave generator 180 is similarly connected.

The first sine wave generator 178 and the second sine wave generator 180 operate at different frequencies. For example, the first sine wave generator 178 operates at 10 MHz while the second sine wave generator 180 operates at 1 MHz.

The dual quad input switch 198 is controlled by input 174 and input 172 that are used to select one of the signals. One of the outputs from the switch is electrically connected to an input of the dual quad output switch 200. Inputs 168 and 170 are connected to the switch 200 to control which of the outputs is selected. The outputs are buffered and then electrically connected to the sensor cell 208, a first reference admittance 210, and a second reference admittance 212. The reference admittances are used for calibration purposes.

As shown in FIG. 6B, the buffered outputs, which drive the cell and the two references, are also electrically connected to a summing circuit 214. The output from the summing circuit 214 is electrically connected, through high pass filter 215, to a mixer 216. This mixer 216 also has a local oscillator input electrically connected to an output from the switch 198 (FIG. 6A). The output of mixer 216 passes through low pass filter 226 and is then electrically connected to an analog-to-digital converter and read by the microcontroller. The output of the mixer 216 has a DC voltage that is proportional to that component of the input voltage signal that is in-phase with the local oscillator.

The sense plate of the sensor cell 208 and the first reference 210 and the second reference 212 of FIG. 6A are electrically connected to a summing current to voltage converter 218 shown in FIG. 6B. The summing current to voltage converter has a low impedance, virtual ground type of input. The output of the summing current-to-voltage converter is electrically connected, through high pass filter 219, to a second mixer 220. The second mixer 220 also has a local oscillator input electrically connected to an output from switch 198 (FIG. 6A). The output of mixer 220 passes through low pass filter 228 and is then electrically connected to an A/D converter and read by the microcontroller. The output of the mixer 220 has a DC voltage that is proportional to that component of the input signal that is in-phase with the local oscillator.

In addition, the current,  $I_F$  from the fill plate on the sensor cell 208 (shown in FIG. 6A) passes through the current to voltage converter 222. This current to voltage converter also has a low impedance, virtual ground type of input. The output of the current to voltage converter 222 is electrically connected, through high pass filter 223, to a third mixer 224. The third mixer 224 also has a local oscillator input that is electrically connected to an output from switch 198. The output of mixer 224 passes through low pass filter 230 and then is electrically connected to an analog to digital converter and read by the microcontroller. This configuration permits monitoring of the admittance of the fill plate relative to that of the sense plate. When this relationship is proportional to the relative sizes of the plates, then the sensor cell 208 is considered full of grain.

The synchronous detection method for measuring complex signals through the use of a local oscillator, a mixer, and

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a low pass filter, as described above, has a very narrow band pass filtering effect, greatly reducing noise influence on the measurement. The virtual ground method of measuring very low-level currents is used to provide the advantage of a substantial reduction in the influence of parasitic elements at the current summing and sensing node.

Returning to FIG. 6A, a thermistor or other temperature sensor is attached to the driven plate of the sensor cell 208. This is only one example of temperature sensor placement. The temperature sensor may also be attached to one of the other plates in the cell. The measurement of temperature allows moisture calculations to be corrected accordingly.

Thus a detailed schematic for the present invention has been shown and described. That which is shown is merely one embodiment of a design according to the present invention. The present invention contemplates variations in the frequencies used, the number of references, the particular electrical components used to perform a particular function or set of functions, and other variations.

Therefore a novel grain moisture sensor has been disclosed. According to one aspect of the invention, the grain moisture sensor provides for the measurement of complex admittance at multiple frequencies. According to another aspect of the invention, the grain moisture sensor is mounted in the grain tank of a combine. According to another aspect of the present invention, the grain moisture sensor is of a sensor cell design that guards the capacitive plates from fringe effects. According to another aspect of the invention, a fill sensor is provided so that accurate determinations can be made as to when the sensor cell is full and ready for measurement.

What is claimed is:

1. A method of grain moisture sensing and measurement comprising:
  - selecting a frequency from a plurality of frequencies;
  - applying the frequency to a parallel plate cell filled with grain;
  - measuring a first complex admittance of the parallel plate cell filled with grain;
  - applying the frequency to a reference;
  - measuring a second complex admittance of the reference; and
  - computing a complex permittivity from the first complex admittance and the second complex admittance.
2. The method of claim 1 wherein the step of computing includes applying a calibration factor to the reference admittance to calculate an empty cell admittance.
3. The method of claim 1 further comprising selecting the second reference admittance from a plurality of reference admittances.

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4. A method of claim 1 further comprising:

measuring real and imaginary components of an excitation voltage having a frequency applied to a driven plate of a parallel plate cell;

measuring real and imaginary components of a sense current sensed at a sense plate of the parallel plate cell; calculating the first complex admittance of the parallel plate cell;

calculating the second complex admittance of a reference admittance; and

calculating a grain complex permittivity.

5. A method of measuring moisture of grain comprising: measuring real and imaginary components of an excitation voltage having a frequency applied to a driven plate of a parallel plate cell;

measuring real and imaginary components of a sense current sensed at a sense plate of the parallel plate cell; calculating a complex admittance of the parallel plate cell; calculating a complex admittance of a reference admittance; and

calculating a grain complex permittivity.

6. The method of claim 5 further comprising using a plurality of references to determine one or more distortion characteristics of measuring the real and imaginary components.

7. The method of claim 6 further comprising correcting for the determined distortion characteristics.

8. The method of claim 6 further comprising correcting for the determined distortion characteristics.

9. The method of claim 5 wherein the reference admittance is selected from a set comprising the parallel plate cell when empty, a capacitive load, and a complex impedance load.

10. The method of claim 5 further comprising changing the frequency of the excitation voltage.

11. The method of claim 5 further comprising selecting the reference admittance.

12. The method of claim 5 further comprising using a plurality of references to determine one or more distortion characteristics of measuring the real and imaginary components.

13. The method of claim 5 wherein the reference admittance is selected from a set comprising the parallel plate cell when empty, a capacitive load, and a complex impedance load.

14. The method of claim 5 further comprising changing the frequency of the excitation voltage.

15. The method of claim 5 further comprising selecting the reference admittance.

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